TAGGING FEASABILITY AND DIVING OF CUVIER'S BEAKED WHALES (*Ziphius cavirostris*) AND BLAINVILLE'S BEAKED WHALES (*Mesoplodon densirostris*) IN HAWAIʻI

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15. SUBJECT TERMS

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ABSTRACT

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INTRODUCTION

Based on their deep-water distributions, long dive times, and the habits of their prey (documented from stomach contents), beaked whales are thought to be deep divers (Mead 1989; Heyning 1989). However, of the 21 recognized species in the family Ziphiidae, information on depth-of-dive and sub-surface behavior has only been published for one, the northern bottlenose whale (*Hyperoodon ampullatus).* Using suction-cup attached time-depth recorders, Hooker and Baird (1999) collected just over 30 hours of dive data from two *H. ampullatus*, documenting regular dives to over 800 m, with a maximum recorded dive depth of 1,453 m. Dives appeared to fall into two discrete categories; short-duration (mean = 11.17 min) shallow dives, and long-duration (mean = 36.98 min) deep dives (Hooker and Baird 1999). Observational information on dive durations is available for several additional species of beaked whales, with median dive times of 28.6 min for Cuvier's beaked whales (*Z. cavirostris),* 20.4 min for *Mesoplodon* spp., and 15.5 min for Baird's beaked whales (*Berardius bairdii*) (Barlow 1999).

Diving habits of beaked whales are of interest both from a biological and a management or conservation perspective. Information on diving behavior can be used to examine habitat use and habitat partitioning, foraging ecology, and diel patterns of behavior. From a management perspective, two issues are particularly relevant for beaked whales. Animals which spend long periods of time beneath the water's surface are likely to be missed during shipboard or aerial surveys. Without taking diving patterns into account, abundance estimates may be negatively biased (see Barlow 1999). In addition, beaked whales appear to be susceptible to impacts from high-intensity sonars (Simmonds and Lopez-Jurado 1991; Frantzis 1998; Balcomb and Claridge 2001; US Dept of Commerce and US Navy 2001; Jepson et al. 2003). Whether their susceptibility to these impacts is due to anatomical or behavioral characteristics, or a combination of these, is unknown. But sound exposure will vary by depth, so the depth at which beaked whales spend their time is important in assessing risk of exposure to high intensity underwater sounds.

The two primary species involved in the multi-species mass strandings associated with naval activities are *Z. cavirostris* and Blainville's beaked whales (*Mesoplodon densirostris*). We have attempted to obtain dive data from both species in Hawaiian waters and report here results from two tag deployments.

METHODS

Field efforts were undertaken during 10 days in September/October 2002 and 13 days in October 2003 off the west coast of the island of Hawaiʻi (19^{o}-20^{o}N, 156^{o}W). Two vessels were operated simultaneously, a 6-m and a 9-m Boston Whaler, each independently searching for beaked whales and other species of cetaceans. Two to five observers on each vessel scanned 360 degrees, and the study area was transited at 15-30 km/hr. Effort data were collected with automatic location information recorded on board each vessel's GPS every 5 minutes. Kriging was used to interpolate depths at 5-minute effort locations (and sightings) using *Surfer* Ver. 6.0 (Golden Software) and digital bathymetry data obtained from NOAA. For each encountered group we recorded species, location and group size, and attempted to obtain identification photographs. Efforts during 2002 were primarily focused on short-finned pilot whale (*Globicephala macrorhynchus*) tagging, and efforts to tag beaked whales were only undertaken during two encounters. During 2003 all beaked whale groups were approached for tagging.

Tags were the same as those used in several other studies of cetacean diving (e.g., Hooker and Baird 1999; Baird et al. 2001, 2002), which included a Mk8 time-depth recorder (Wildlife Computers, Redmond, WA), and a VHF radio transmitter (Telonics, Mesa, AZ), housed in a custom-made syntactic foam body, and attached to a whale with an 8-cm diameter suction cup. Tags weighed approximately 450 grams. Depth and velocity were recorded at one-second intervals, with a depth resolution of 1 m. Velocity readings were uncalibrated and are thus presented as relative velocity.

Tags were deployed by crossbow (Barnett RX-150). Once tagged, whales were followed using VHF signals and visual observations. Information on location, group size, distance of the nearest neighbor to the tagged animal, and speed and direction of travel, were recorded at each surfacing. Sex and age of tagged animals were determined based on pigmentation patterns, body scaring, presence or absence of erupted teeth, and body size (Heyning 1989; Mead 1989). Tags were recovered using VHF signals, and data were downloaded to a PC using Mk8Host (Wildlife Computers). Temperature-related drift in depth values (see Hooker and Baird 2001) was corrected with the program Instrument Helper (Wildlife Computers). Rates of descent and ascent were calculated using periods of relatively constant descent/ascent lasting at least 25% of the period of descent/ascent.

RESULTS

During 2002 we had 154 hours of search effort, covering 1,649 km of trackline, while during 2003 we had 173 hours of search effort covering 2,495 hours of trackline (Figure 1). Most of the effort was in sea conditions of Beaufort 3 or less. Approximately 80% of survey effort was in water depths ranging from 500-2,000 m (depth mean = 1,463 m, SD = 752 m, median = 1,226 m), with some effort out to 4,500 m (Figure 2). Beaked whales were encountered on 11 occasions, with five encounters in 2002 and six encounters in 2003. Three encounters were with *M. densirostris* (group size range 1-9, mean = 3.7, SD = 4.62) and eight encounters were with *Z. cavirostris* (group size range 1-5, mean = 2.9, SD = 1.36). Depth distributions of both species differed from the depth distribution of effort (Mann-Whitney U-test, p = 0.004 *Z. cavirostris* vs. effort; p = 0.01 *M. densirostris* vs. effort), with *Z. cavirostris* found in significantly deeper water (median = 1,933 m, mean = 2,117 m, SD = 540 m) and *M. densirostris* found in significantly shallower water (median = 587 m, mean = 623 m, SD = 156 m) than our search effort.

We approached beaked whales for the purposes of tagging during eight encounters, though actual tagging attempts were made during only four encounters, two each with *Z. cavirostris* and *M. densirostris*. There were seven tagging attempts, three with *Z. cavirostris* and four with *M. densirostris*. Tags were successfully deployed in two of the seven attempts: one on an adult male *M. densirostris* (on 24 September 2002), and one on an adult female *Z. cavirostris* (on 27 September 2002). Reactions to tagging consisted of a fast dive (the *Z. cavirostris*) or a tail slap and a fast dive (the *M. densirostris)*; in both cases tagged whales returned to pre-tagging behavior when next seen (on the surfacing following tagging), remaining with and exhibiting similar behavior to other whales in the group. Both successful taggings were of whales in larger groups (nine *M. densirostris*; five *Z. cavirostris*).

The *Z. cavirostris* tag remained attached for a minimum of 7 hours, during which time the tagged animal was followed. Failure of the VHF transmitter, confirmed through visual observation of the tag on the whale with no VHF signals, resulted in loss of this tag. During the time the tagged whale was followed, durations of most of the long dives (dives > 2 minutes) were documented, and ranged from 19-87 minutes (n = 12, mean = 31.5 min, median = 22.5 min, SD = 21.9).

The tagged *M. densirostris* was the only adult male in a group of nine individuals; four of the individuals in the group appeared to be adult females, and the remaining four were juveniles. This tag remained attached for 2.09 h, and the tagged animal was followed until the last surfacing before the tag fell off (1.88 h after deployment). Group size remained constant for the duration of the encounter, and direction of travel was inconsistent. All individuals remained within approximately 20 m of each other when at the surface, and all individuals surfaced within 1-2 minutes of each in discrete surfacing bouts. Distance to its nearest neighbor was documented for the tagged whale during 6 of the 10 surfacing bouts, and it remained within 1 to 5 m of its nearest neighbor. Based on all these characteristics, behavior of the group was considered to be "social" during the encounter. Behavior of the group during and following the last documented dive is not known (the group was not seen again). Bottom depth in the vicinity of the tagged whale was between 570-914 m during the duration of the encounter.

Thirteen discrete dives (>3 m) were documented from the *M. densirostris* TDR deployment. Dive durations (Table 1) were only available for 12 of these dives, as the tag detached part way through the 13th dive. Maximum depth was determined for all 13 dives (Table 1). On the 13th dive the whale had leveled off 3.6 min prior to tag detachment, and thus was unlikely to dive deeper. Using the rate of descent as a proxy for the rate of ascent, minimum duration of the 13th dive was estimated. As the ascent had not yet begun, and the descent rate was generally higher than ascent rate on the other dives (Table 1), the estimated duration of the 13th dive is likely to be negatively biased. The proportion of time spent at different depths in the water column is shown in Table 2 and Figure 3. Velocity varied with depth (Figure 4). Velocity in the top 20 m of the water column (median = 1.2) was significantly higher (Mann-Whitney U-test, $p<0.0001$) than velocity at greater depths (median = 0.9), though patterns in velocity were different between the shallow dives and the single deep dive (Figure 5).

DISCUSSION

We were able to successfully tag both *Z. cavirostris* and *M. densirostris*, the first tags deployed on either species. Tagging success rate (two out of seven attempts) was substantially higher than for *H. ampullatus* (five out of 84 attempts; Hooker and Baird 1999) for a variety of reasons. The vessel used for the *H. ampullatus* work was a sailboat and was not particularly maneuverable at slow speeds. In addition, *H. ampullatus* often lie at the surface with only part of their back exposed, and many tagging attempts resulted in the tag skipping off the whale's body (see Hooker et al. 2001). Reactions of tagged whales, and depth and velocity data recorded from the one tag recovered (Figure 4) suggests that reactions to tagging are only short-term (ie., minutes), and behavior of tagged whales should be representative.

Although only one of the two tags was recovered, our radio-tag data from the *Z. cavirostris* did allow for recording of dive durations over an extended (7 h) period, including documentation of a dive up to 87 minutes in duration. The tagged *Z. cavirostris* was in an area with a bottom depth of approximately 2,000 m, and we believe the VHF transmitter failure was a result of repeated dives to great depth (a factor likely responsible for the failure or loss of three of the five tags Hooker and Baird (1999) deployed on *H. ampullatus*). Relatively little dive duration information is available for *Z. cavirostris* (see Barlow 1999); our median dive duration (22.5 min) is lower than the median dive time (28.6 min) reported by Barlow (1999).

For the tag recovered from the *M. densirostris*, while the sample size is small (one individual, 2.09 h of dive data), these represent the first depth-of-dive data available for *M. densirostris*, and the first for any of the 14 recognized species of *Mesoplodon*. During the period the whale was followed it was generally engaged in social behavior, and thus the diving patterns should be interpreted in this context. The whale spent most of its time in the top 100 m of the water column (Table 2, Figure 3), though one deep dive was documented. Several lines of evidence suggest that the behavioral state was different for the period of the shallow dives versus the one deep dive. Rates of descent and ascent on the shallow dives (Table 1) were low (mean = 0.41 and 0.38 m/sec), similar to those reported for shallow dives of *H. ampullatus*, while the descent rate for the deeper dive (1.49 m/sec) was much greater, also similar to findings for *H. ampullatus* (Hooker and Baird 1999). Velocity during descents on shallow dives generally decreased over the descent (Figure 5), while velocity during the descent of the one deep dive followed a more complex pattern (Figure 5). Velocity was initially high and decreased over the first 160 m of the descent, there was an extended period where velocity was low (with frequent periods where the velocity meter stalled, despite the constant and relatively high rate of descent for this dive; Table 1, Figure 4), and then a period at the bottom of the dive where velocity was higher and more variable. The extended period of low velocity may represent gliding behavior, as has been documented for a number of other species of diving mammals (Williams et al. 2000). The velocity and depth profile for this dive suggests that its purpose was different from the shallower dives documented earlier and likely was reflecting a switch to foraging behavior.

Information on the proportion of time spent in the upper parts of the water column (Table 2, Figure 3) may be relevant for survey calibration (cf. Barlow 1999), although whether time in the upper 1-2 m or 3-4 m is considered will depend on the survey platform (ship-based vs. aerial surveys, respectively). Caution should be taken using the current data for such purposes, as social behavior is likely to involve more time near the surface than foraging behavior (see above).

Little is known of the diet of *M. densirostris* (see review by MacLeod et al. 2003), but the limited information available suggests this species feeds on deep-water fish and squid. Given the bottom depth in the area where the tagged whale was, the 890 m dive was likely to, or close to, the bottom, supporting the evidence from stomach content analyses that *M. densirostris* may feed at or close to the bottom.

While dive data from only a single whale was obtained, we were able to demonstrate that obtaining dive data from these species of beaked whales is feasible, although substantial levels of effort are required. Diving patterns are likely to vary with group size and behavioral state, and further efforts are clearly needed to obtain dive data from both of these species.

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Table 1. Dive characteristics for a single tagged adult male *M. densirostris*. Mean and SD shown except for the single deep dive, where actual value is shown.

Dive type	N	Duration (min)	Maximum depth (m)	Descent rate (m/sec)	Ascent rate (m/sec)
Shallow	12	7.47 (2.49)	58.6 (35.5)	0.41 (0.14)	0.38 (0.14)
Deep	1	23.3*	890	1.49	na

*Estimate determined using rate of descent as proxy for rate of ascent.

Table 2. Percentage of time spent in different portions of the water column for a tagged adult male *M. densirostris* over a 2.09 hour period.

Top 10 m		Top 100 m		All	
Depth range (m)	Percentage of time	Depth range (m)	Percentage of time	Depth range (m)	Percentage of time
0-1	11.17	0-10	26.05	0-100	87.77
1-2	5.34	11-20	23.58	101-200	3.24
2-3	2.32	21-30	7.20	201-300	0.86
3-4	1.27	31-40	5.72	301-400	0.77
4-5	0.78	41-50	4.57	401-500	0.82
5-6	0.81	51-60	4.83	501-600	0.90
6-7	0.88	61-70	5.07	601-700	1.14
7-8	1.21	71-80	2.98	701-800	0.79
8-9	0.98	81-90	4.54	801-900	3.71
9-10	1.29	91-100	3.23		

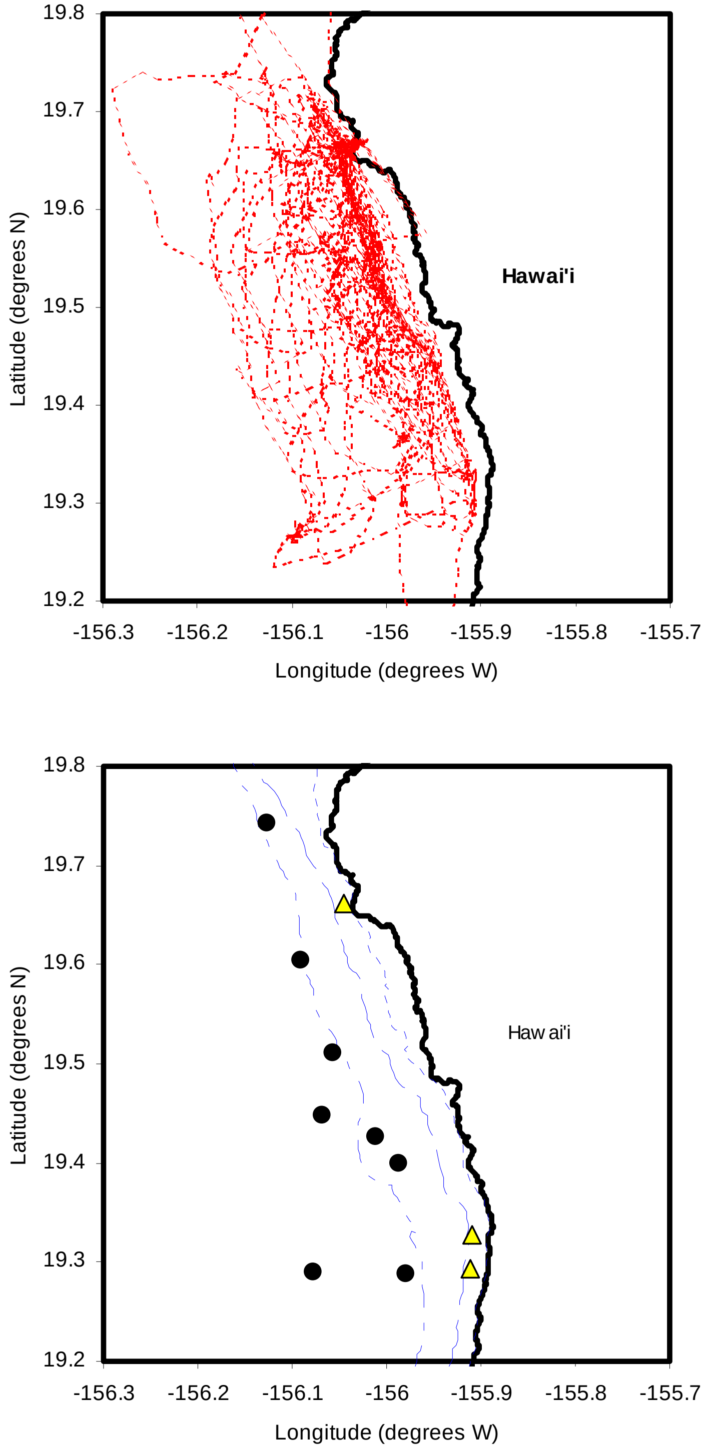

Figure 1. Survey effort (top) and sightings (bottom) of *Z. cavirostris* (●) and *M. densirostris* (△) off the island of Hawaiʻi in September/October 2002 and October 2003. The 100 m, 1,000 m and 2,000 m depth contours are shown in the bottom map.

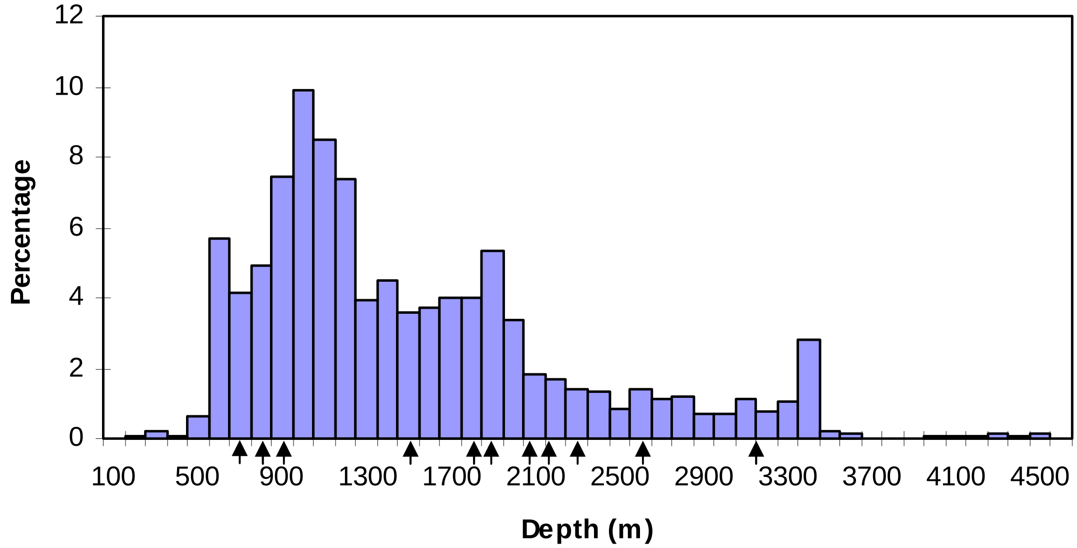

Figure 2. Depth distribution of search effort from 5-minute GPS locations. Each x-axis tick mark represents a 100-m depth bin (e.g., 1-100 m, 101-200 m, etc). Initial water depths at which beaked whales were encountered are shown as arrows along the depth axis, with the three left-hand most points being *M. densirostris*. Given the steep slope of the study area (see Figure 1), locations in a particular depth bin likely also represent coverage in one or more adjacent bins.

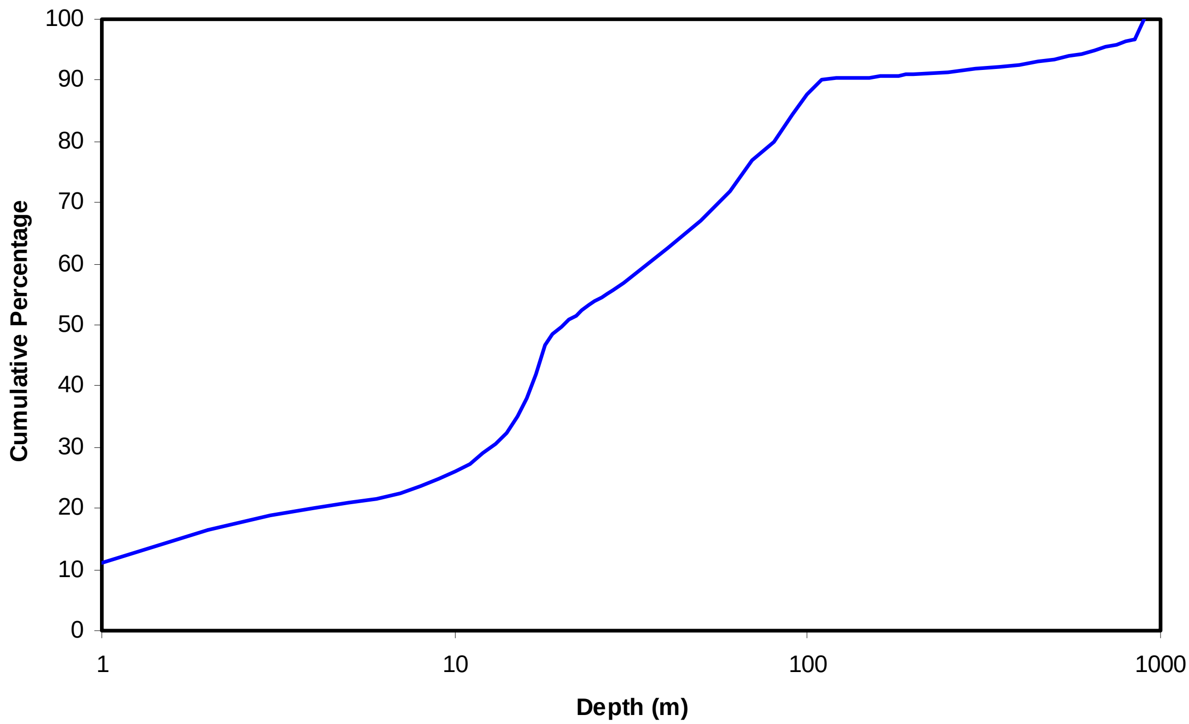

Figure 3. Cumulative percentage of time spent at different depths in the water column for an adult male *M. densirostris.* Depth is shown on a log scale.

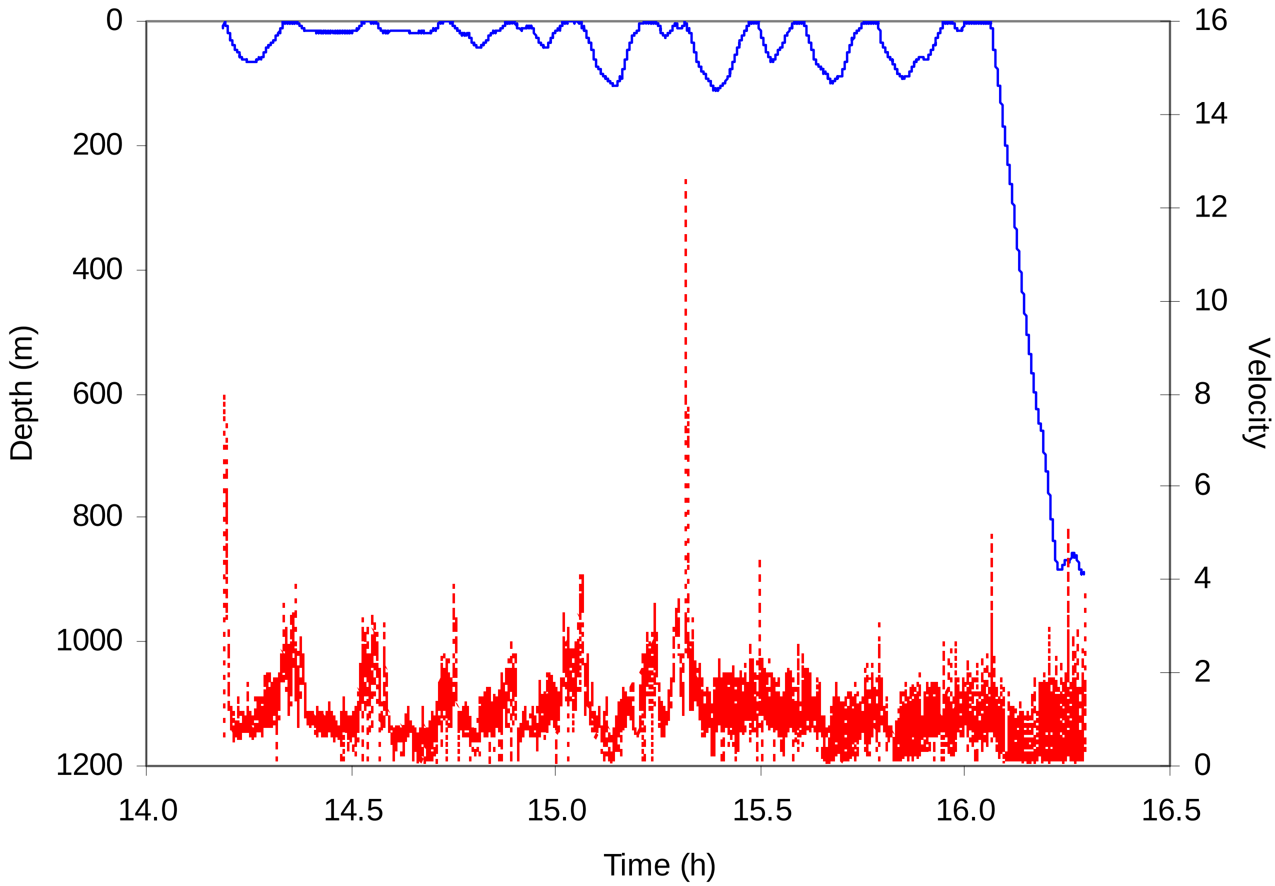

Figure 4. Depth (top, solid line) and velocity (bottom, dashed line) data for an adult male *M. densirostris*. No units are shown for velocity, as velocity varies with body size and position of the tag on the body. The first velocity spike is likely a response to tagging; the cause of the highest spike (at ~15.3 h) is unknown.

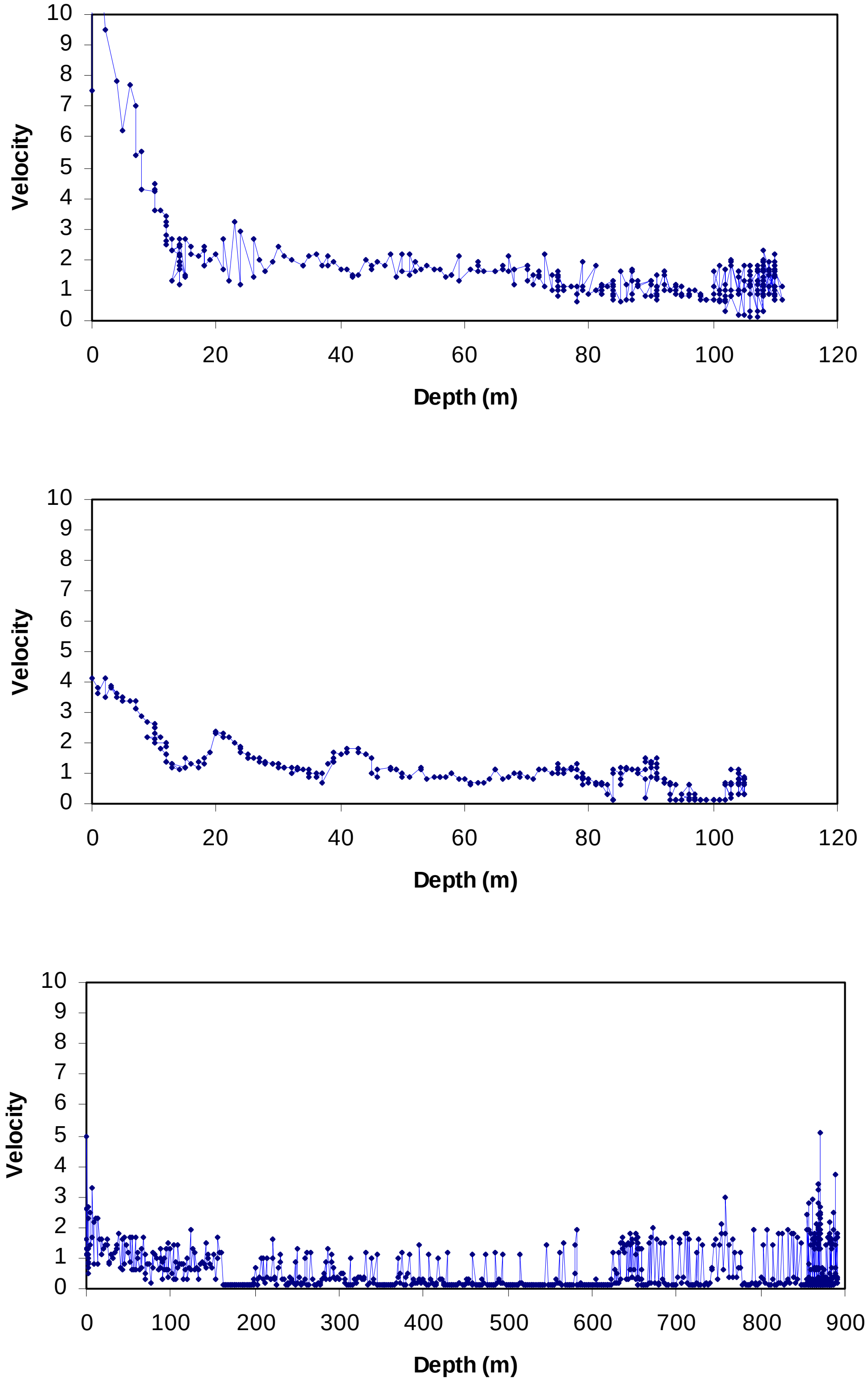

Figure 5. Velocity versus depth during the descent for two shallow (top and middle) and one deep (bottom) dives. During shallow dives velocity is high initially, and then slowly decreases to the lowest velocity near the bottom of the dive. During the one deep dive velocity was high initially (in the top 160 m), was low during the longest portion of the descent, and then increased at the bottom of the dive. The higher rate of descent on the deep dive (Table 1) suggests angle of diving was much greater than for the shallow dives.